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RESEARCH MEMORANDUM

PERFORMANCE OF A SUPERSONIC RAMP INLET WITH INTERNAL BOUNDARY-LAYER SCOOP

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An experimental investigation to determine the effect on inlet performance of several boundary-layer scoops mounted inside a ramp-type inlet was conducted in the Lewis 8- by 6-foot supersonic wind tunnel at Mach numbers 1.5, 1.8, and 2.0.

Inlet peak pressure recovery at Mach number 2.0 was increased from 0.83 for no scoop to 0.93 for the largest scoop investigated. Inlet peak recovery was constant for scoops larger than those required to remove the ramp boundary layer. If bypass drags associated with near-axial discharge of the scoop mass flow are considered, and any effects of inlet size are neglected, increases of 10 percent of the available thrust of the inlet with no scoop are indicated at a Mach number of 2.0. For high drag mass flow spillage, at least 3-percent gain in available thrust may still be realized. Maximum gains at Mach numbers 1.8 and 1.5 were of the order of 5 percent of the available thrust.

INTRODUCTION

Efficient side-inlet performance generally necessitates removal of accumulated fuselage boundary layer to prevent the entrance of low-energy air into the inlet and to prevent any harmful effects of boundary-layer shock interaction. With increasing free-stream Mach numbers, inlet terminal shocks have been observed to interact with the boundary layer on inlet compression surfaces, even though the fuselage boundary layer ahead of the inlet is removed (refs. 1 to 4). In order to determine the effectiveness of a scoop in removing this ramp boundary layer, an investigation was conducted in the NACA Lewis 8- by 6-foot supersonic wind tunnel on a 14° ramp-type inlet similar to one on which shock-induced ramp boundary-layer separation was observed (ref. 4). The inlet was investigated in the free stream at zero angle of attack at Mach numbers 1.5, 1.8, and 2.0 with a series of internal boundary-layer-scoop heights from zero to 0.266 inch (1/4 duct height).

APPARATUS AND PROCEDURE

A detailed sketch of the model and its support is shown in figure 1,
and a photograph of the model in the tunnel appears in figure 2. A rec-
tangular 14° ramp inlet of the type reported in reference 4 was mounted
by means of a support strut at zero angle of attack in the Lewis 8- by
6-foot supersonic wind tunnel. The inlet was located in the free stream
simulating the case of complete removal of fuselage boundary layer. The
internal geometry included a boundary-layer-removal system of the scoop
type. Variations in scoop height were accomplished by vertical adjust- 3453
ments made to the diffuser floor section. Resultant main-duct area vari-
ations are shown in figure 3. It may be noted that some internal con-
traction exists for this inlet. Maximum scoop height tested was approx-
imately one-fourth the duct height at the scoop lip (model station 0.75).
Ramp boundary-layer mass flow captured by the bleed scoop was ducted
through the mounting plate and exhausted to an effective base pressure.
Scoop inlet-to-exit area ratio was approximately 1/3 for all scoops
tested.

Pressure instrumentation consisted of total-pressure tubes and wall static-pressure orifices in the diffuser at model station 21.5. Similar instrumentation was installed at station 2.0 for a portion of the test.

Inlet mass flow was varied by means of a remotely controlled movable exit plug. Main-duct discharge mass-flow ratio was determined from the average total pressure and the known area ratio between the diffuser-discharge station and the exit plug, which was assumed to be choked. Average total pressure was calculated by area-weighting the total-pressure measurements.

Seven scoop heights h, ranging from 0.06 to 0.25 of the duct height d were tested in addition to the unmodified inlet ($h = 0$). Main-duct mass-flow ratio was varied at free-stream Mach numbers 1.5, 1.8, and 2.0. Reynolds number varied from 4×10^6 to 5×10^6 per foot.

SYMBOLS

The following symbols are used in this report:

A_i inlet capture area, 0.0244 sq ft

D configuration drag

D_a incremental drag, $D_b - D$

d duct height at scoop lip (model station 0.75), 1.06 in.

F internal thrust of turbojet-engine and inlet combination

h boundary-layer-scoop height

m_2/m_0 main-duct mass-flow ratio, $\frac{\text{main-duct mass flow}}{\rho_0 V_0 A_1}$

P total pressure

V velocity, ft/sec

ρ mass density

Subscripts:

b basic configuration, h = 0

0 free stream

2 diffuser-discharge survey station, model station 21.5

RESULTS AND DISCUSSION

Typical variations of inlet-diffuser pressure recovery with main-duct mass-flow ratio are presented in figure 4. Cross plots of the variation of inlet peak and critical pressure recovery with scoop-height parameter are presented in figure 5. Inlet critical pressure recovery at the higher Mach numbers reached a maximum, then decreased before peak recovery reached its maximum. At all Mach numbers, critical pressure recovery was improved 4 to 5 percent; however, the largest gains were noted for peak recoveries at Mach number 1.8, and especially at Mach number 2.0, where peak recovery was increased from 0.83 for no scoop (no boundary-layer removal) to 0.93 for the largest scoop tested (complete removal of the ramp boundary layer behind the inlet terminal shock). Main-duct mass-flow ratio was correspondingly reduced nearly 40 percent. The existence of these high recoveries at both Mach numbers 1.8 and 2.0 is not explainable from theoretical two-dimensional shock-wave considerations of a simple 14° ramp-type inlet, but is possible only when the effects of a second oblique shock emanating from the shock boundary-layer-interaction region on the ramp surface are included (shown in ref. 4 in a schlieren photograph of a similar inlet). Calculations of the pressure recovery based on this two-oblique- and one-normal-shock system have been verified by data obtained with total-pressure tubes located inside the inlet cowl.

At Mach numbers 1.8 and 1.5, peak recovery was constant above h/d of 0.18 and 0.12, respectively, indicating that, for these scoop heights, all the low-energy boundary layer was removed and that, for further increases in scoop height, high-energy air was needlessly discharged.

Since the scoop height above which peak recovery was constant increased with increasing Mach number, it appears that the boundary-layer thickness, or separation thickness, increased with Mach number in accordance with the increasing pressure rise across the inlet terminal shock.

The range of inlet stability at Mach number 2.0 (fig. 4(c)) decreased with increasing boundary-layer-scoop-height parameter h/d from 0 to 0.18, then increased with further increases in scoop height. No improvement was noted in the maximum range of stability at either Mach 3453
number 2.0 or 1.8. It is clear, however, that a variable scoop could be employed in a manner similar to a bypass to maintain diffuser stability to lower diffuser-discharge mass flows.

The gains in inlet pressure recovery are in part offset by drag increases associated with the boundary-layer removal. Therefore, estimates were made to determine the net effect on the available thrust. Thrust ratios were obtained for a typical turbojet engine. Bypass drag coefficients reported in reference 5 were assigned to the supercritical bleed mass flows on the basis of two inlets, while additive drag values from the two-engine configuration of reference 4 were assigned to subcritical mass-flow spillage. Each configuration was investigated over the mass-flow range, and the ratio of maximum thrust minus incremental drag $(F - D_a)$ to total thrust F_b of the unmodified inlet $(h = 0)$ is presented in figure 6 as a function of h/d (solid lines). Inlet matching at each scoop height requires inlet sizing in proportion to the mass flow bled and spilled at the desired match point, and resulting changes in configuration drag were assumed in the calculation of the dashed lines of figure 6.

The effect of inlet sizing, appreciable here, would be expected to decrease for configurations on which the inlets could be modified without affecting the projected frontal area. If the effect of inlet sizing is neglected and bypass drags associated with near-axial discharge are considered, an increase of 10 percent of the available thrust of the unmodified configuration $(h = 0)$ is indicated at Mach number 2.0, while gains of 5 percent are shown for the lower Mach numbers. Calculations of drag assuming complete loss of the free-stream momentum of the mass flow bypassed through the boundary-layer scoop indicate that increases of 3 percent in available thrust at Mach number 2.0 can still be realized.

It appears from figure 6 that an h/d near 0.21 would be optimum over the Mach number range investigated. Although maximum $F - D_a$ occurs at slightly different scoop heights for the lower Mach numbers, little would be gained by making the scoop height adjustable.

SUMMARY OF RESULTS

An experimental investigation to determine the effects on inlet performance of a series of boundary-layer scoops mounted inside a ramp-type inlet was conducted in the Lewis 8- by 6-foot supersonic wind tunnel at Mach numbers from 1.5 to 2.0. The following results were obtained:

1. If bypass drags associated with near-axial discharge of the scoop mass flow are considered, and any effects of inlet size are neglected, increases of 10 percent of the available thrust of the inlet with no scoop are indicated at Mach number 2.0. For high-drag mass-flow spillage, at least 3-percent gain in available thrust may be realized. Maximum gains at Mach numbers 1.8 and 1.5 are of the order of 5 percent of the available thrust of the unmodified configurations.

2. Inlet peak pressure recovery at Mach number 2.0 increased from 0.83 for no boundary-layer removal to 0.93 for complete removal of the ramp boundary layer behind the inlet terminal shock.

3. Inlet peak recovery was constant for scoop heights above that required to remove all the boundary layer.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, September 10, 1954

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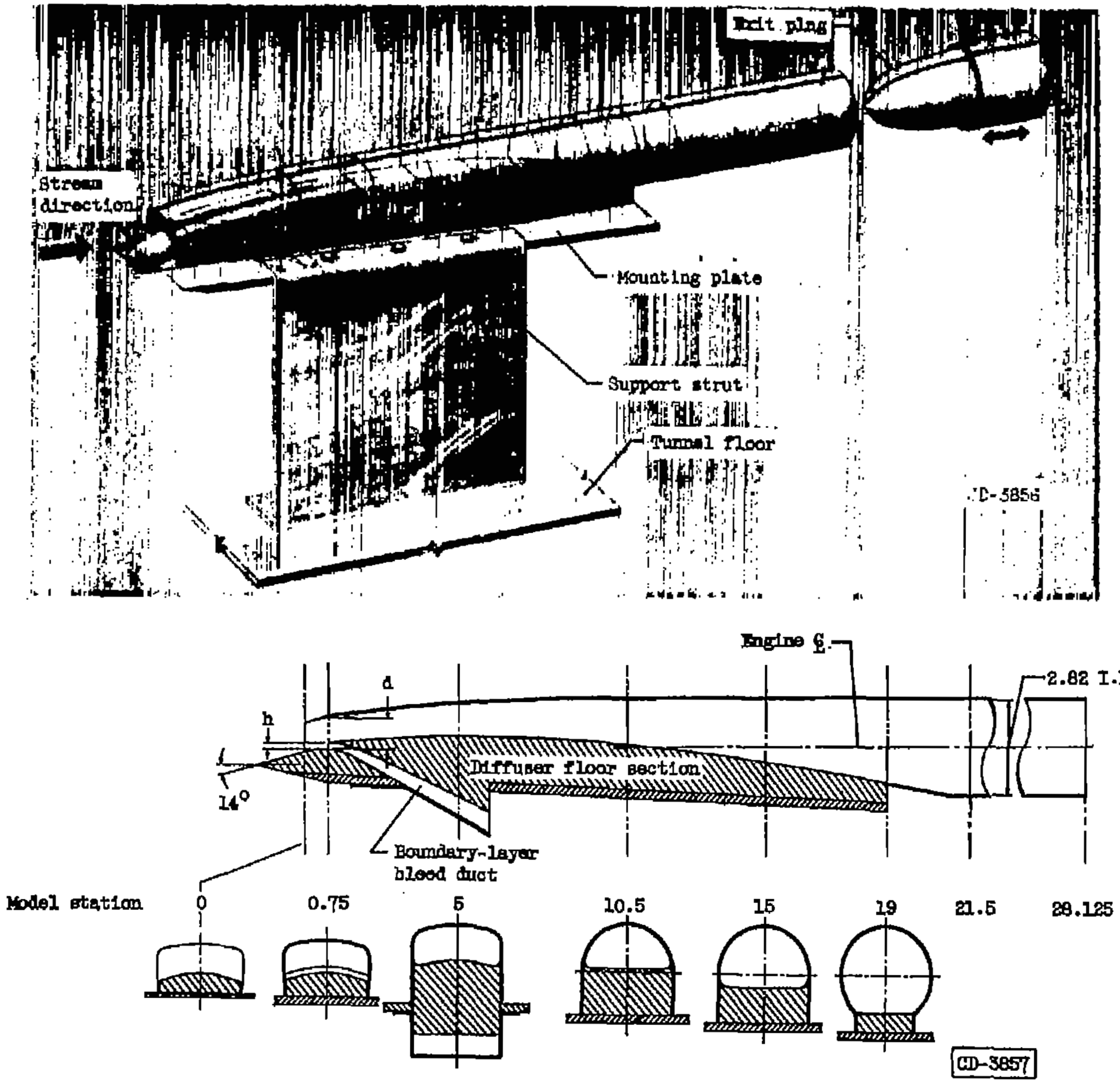

Figure 1. - Diagram of model with representative cross sections (all dimensions in inches).

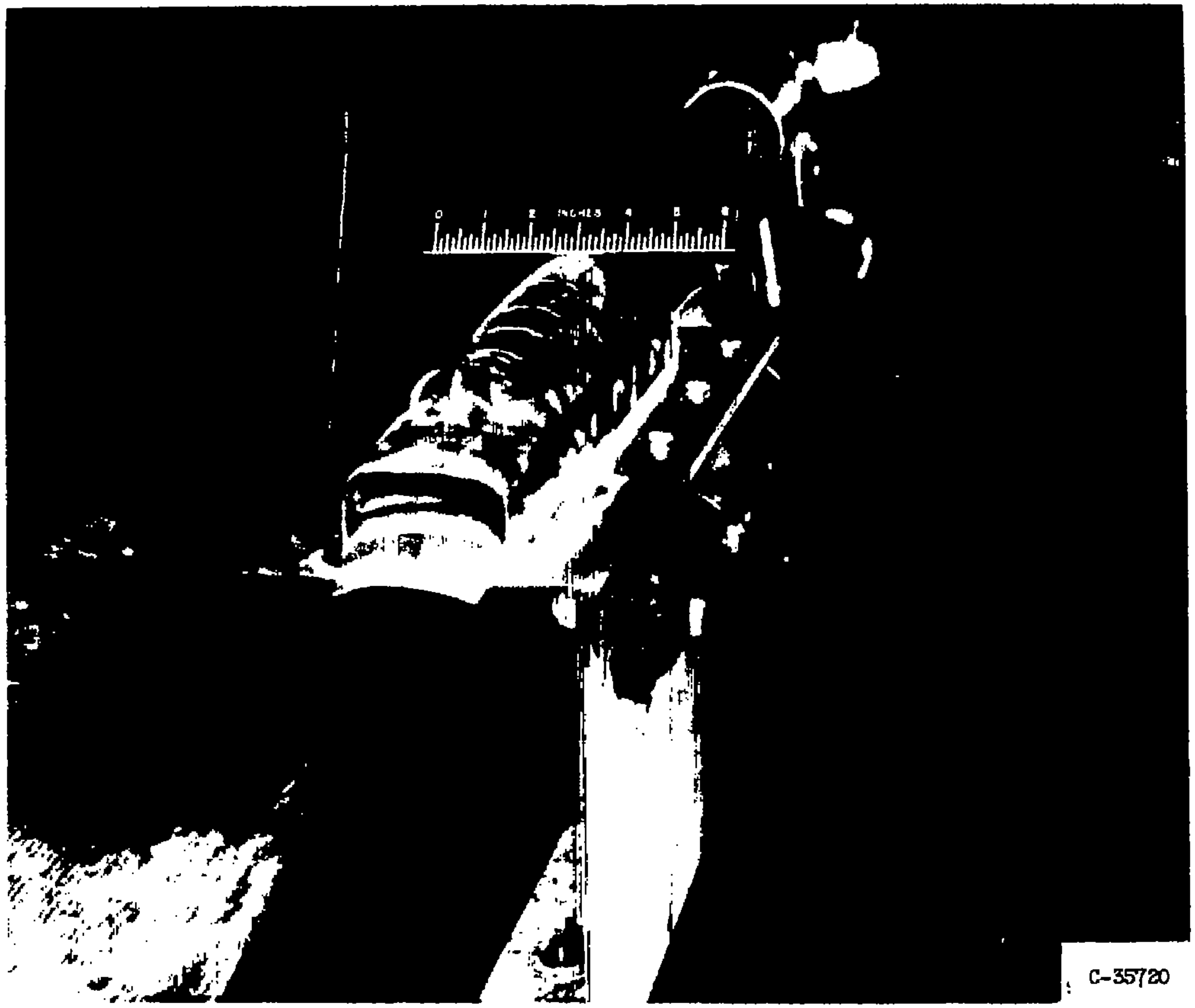

Figure 2. - Model installed in 8- by 6-foot supersonic wind tunnel.

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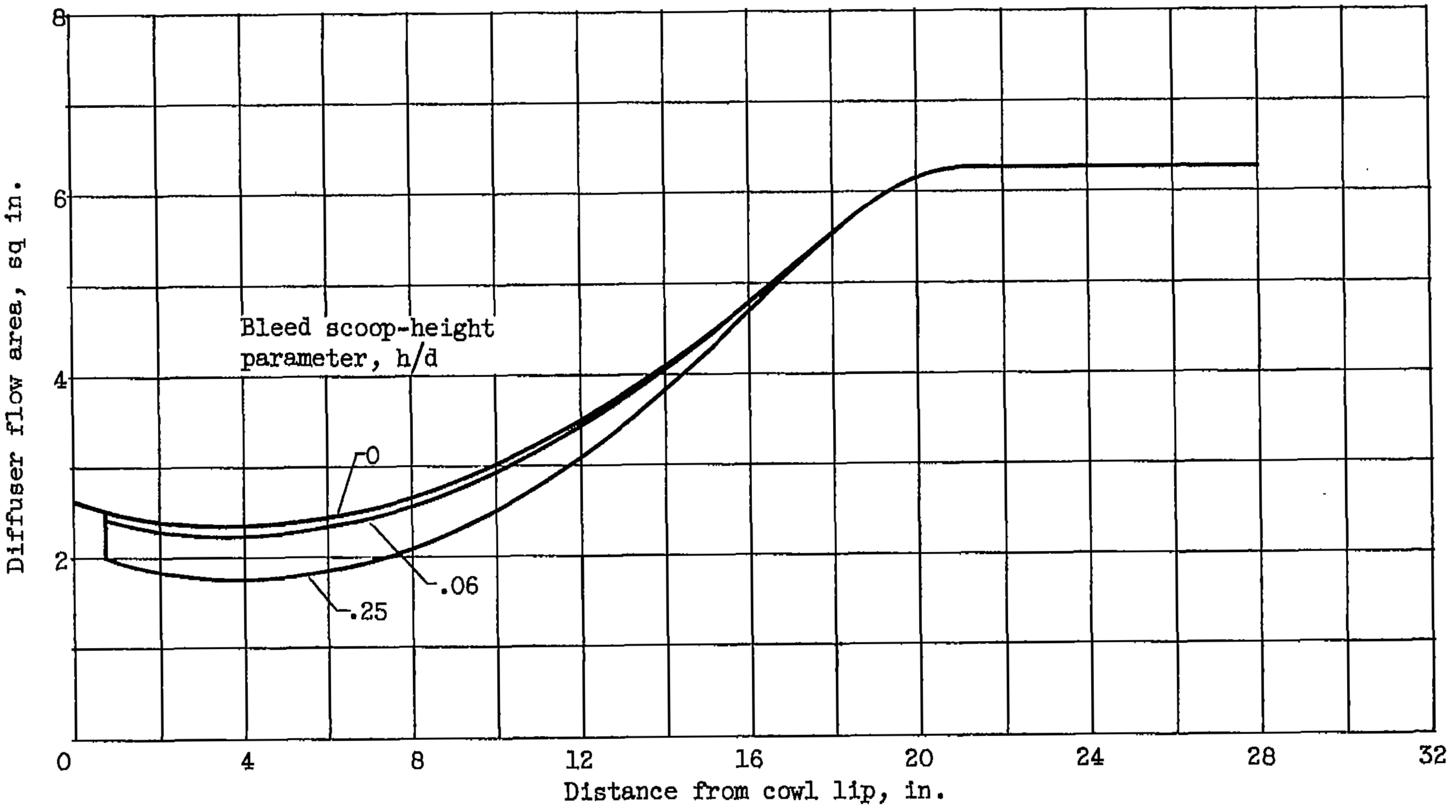

Figure 3. - Subsonic-diffuser area variations.

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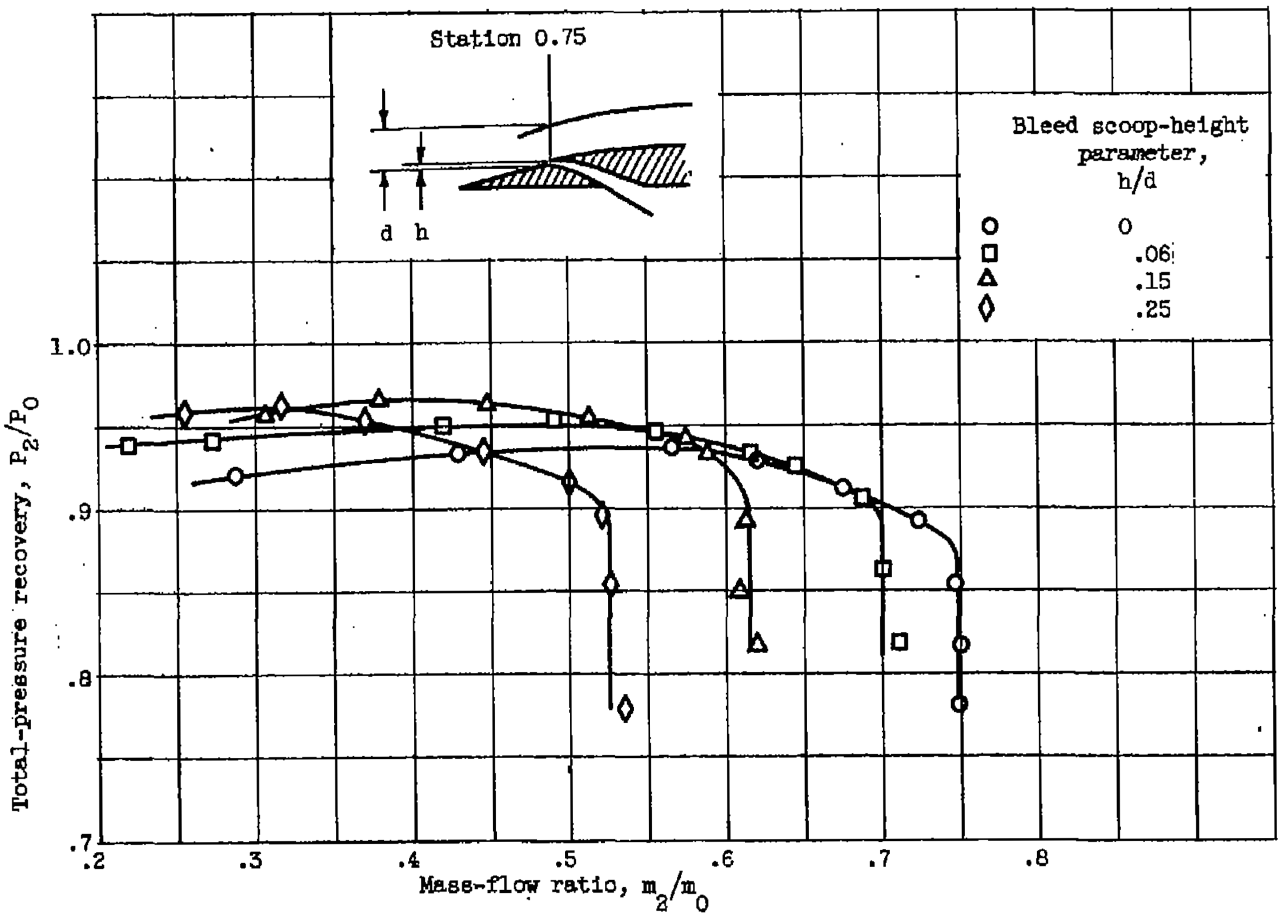
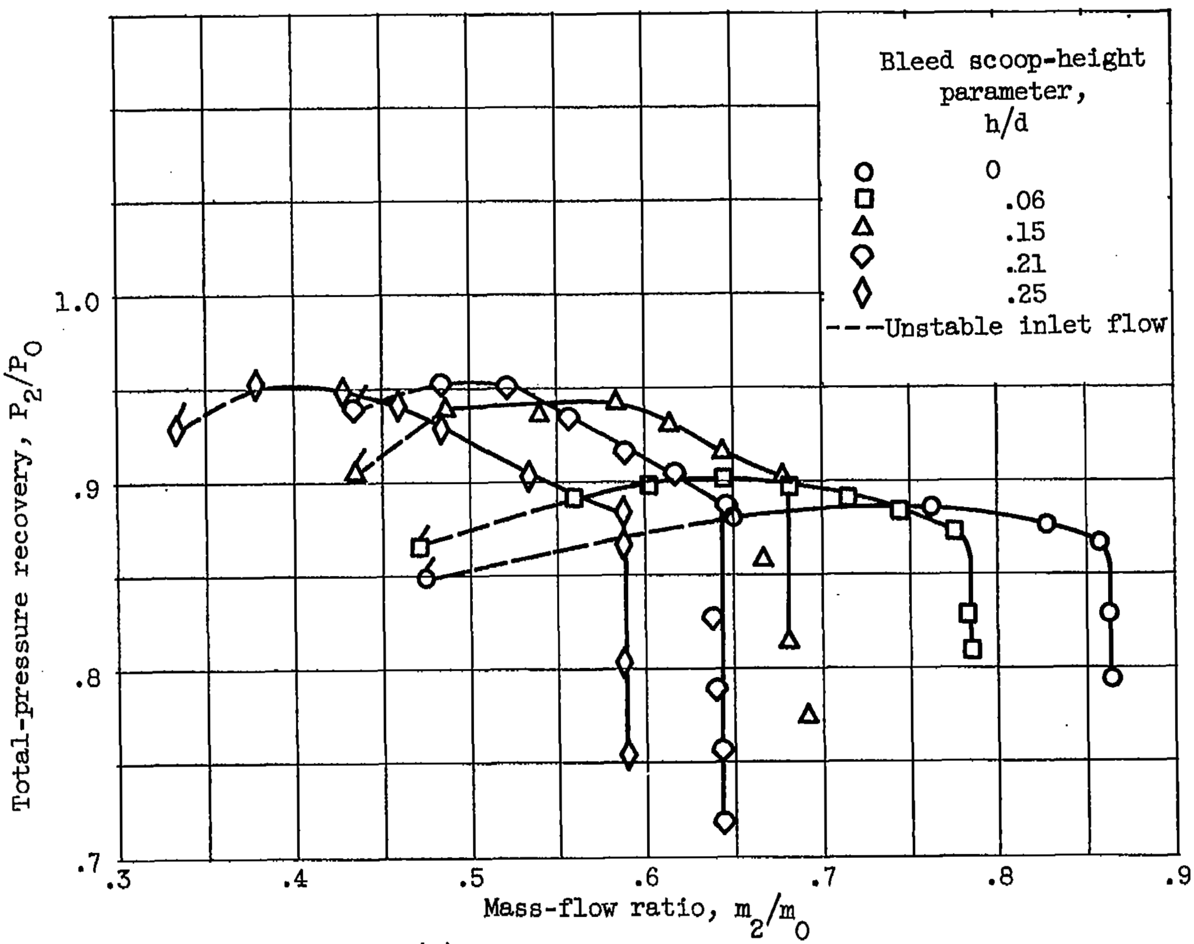


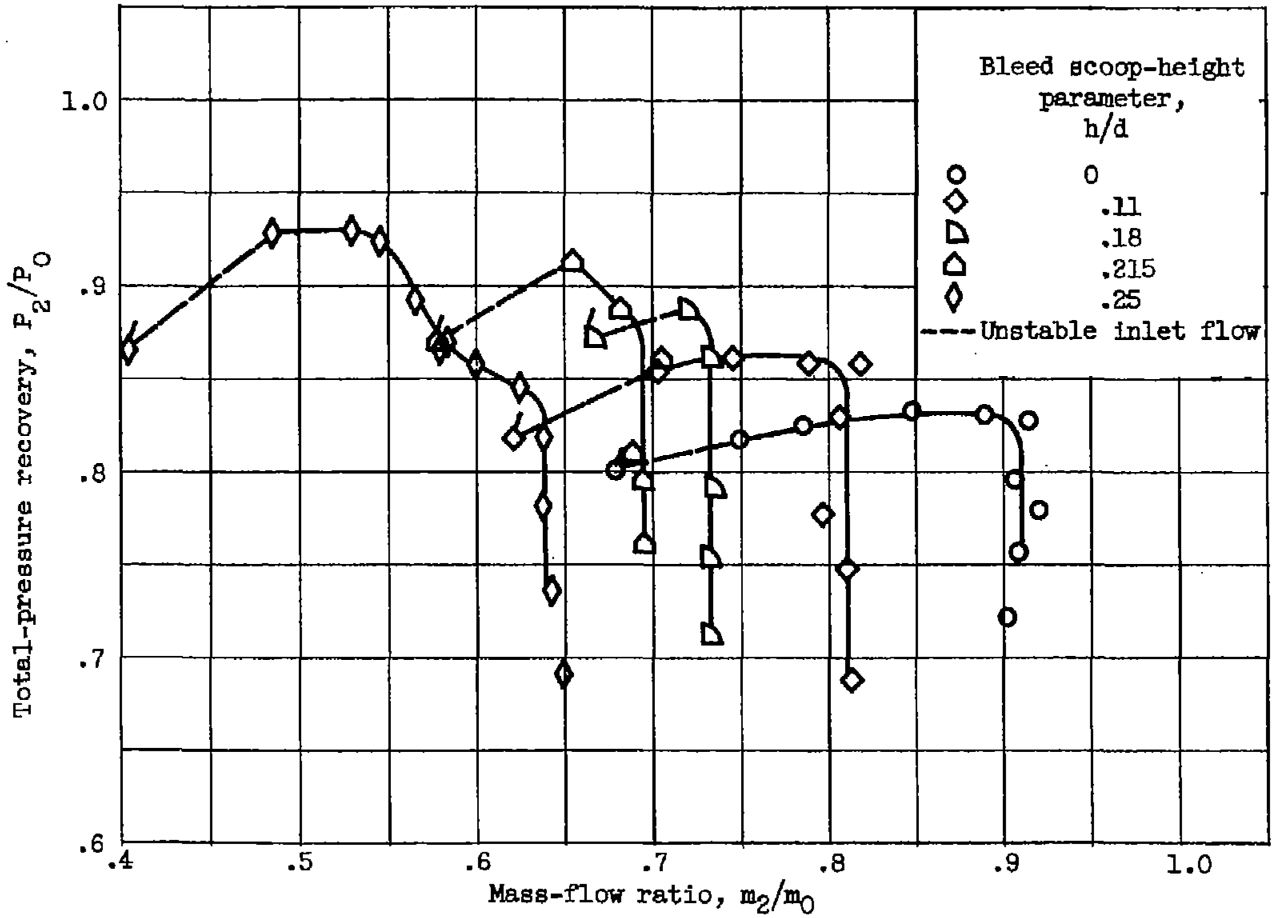
(a) Free-stream Mach number, 1.5.

Figure 4. - Effect of internal-bleed scoop height on inlet performance.



(b) Free-stream Mach number, 1.8.

Figure 4. - Continued. Effect of internal-bleed scoop height on inlet performance.



(c) Free-stream Mach number, 2.0.

Figure 4. - Concluded. Effect of internal-bleed scoop height on inlet performance.

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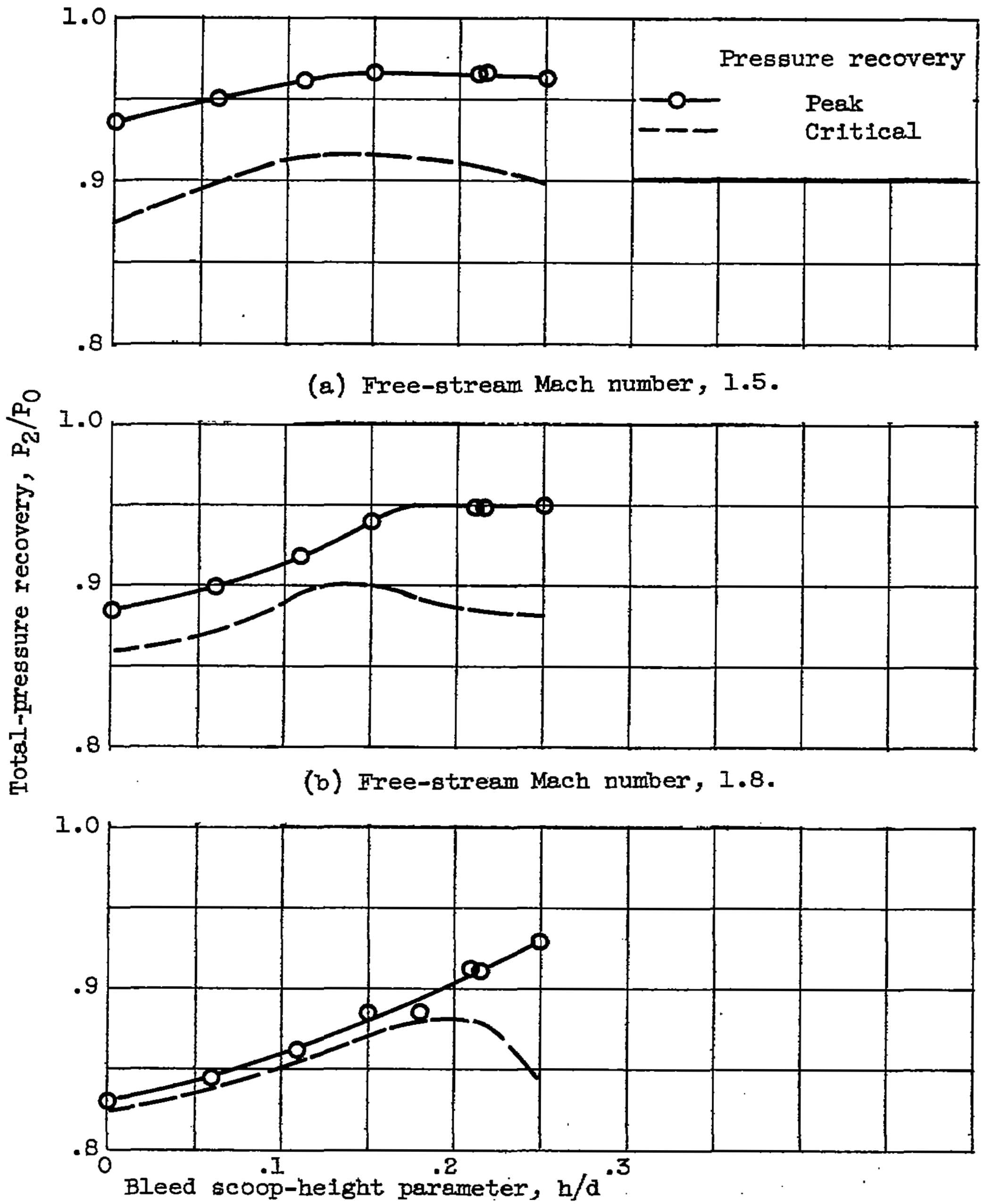

(a) Free-stream Mach number, 1.5.

(b) Free-stream Mach number, 1.8.

(c) Free stream Mach number, 2.0.

Figure 5. - Inlet peak and critical pressure recovery.

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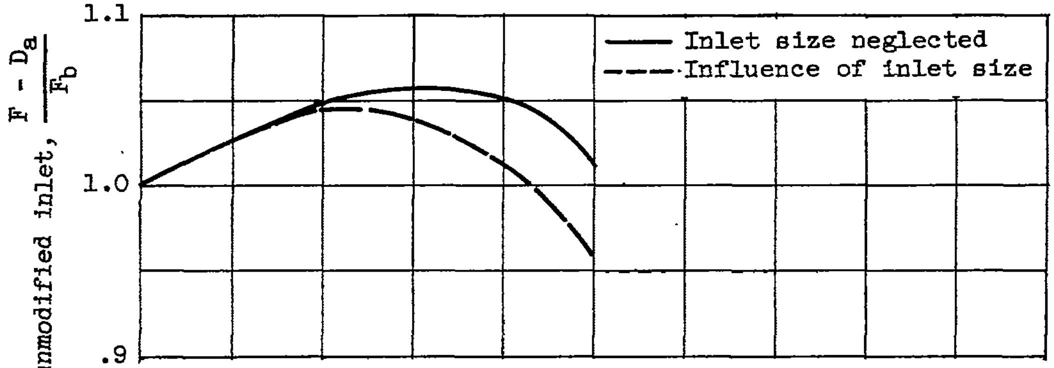
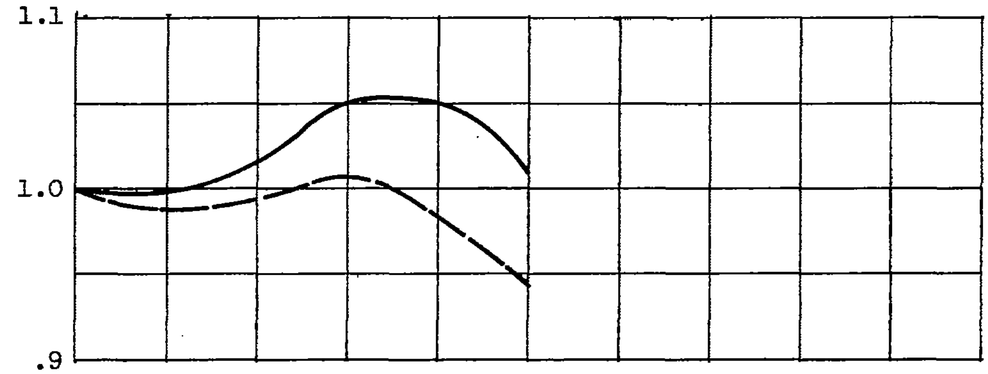
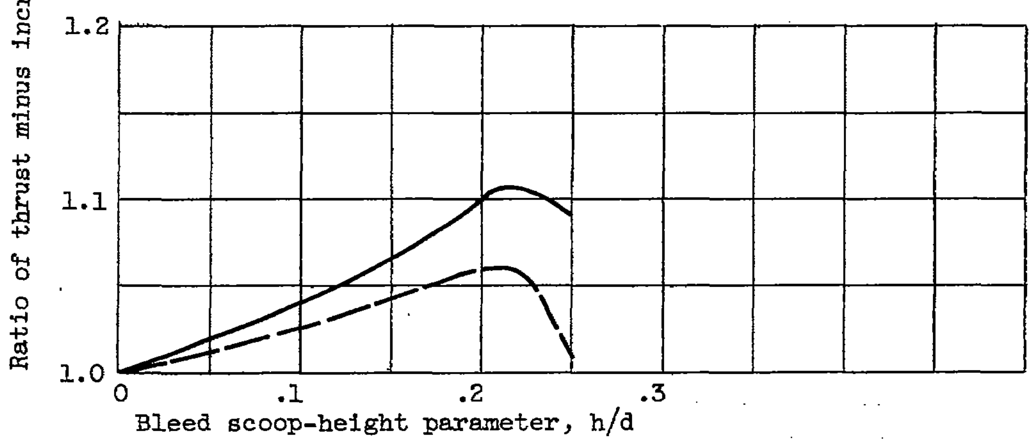


(a) Free-stream Mach number, 1.5.



(b) Free-stream Mach number, 1.8.



(c) Free-stream Mach number, 2.0.

Figure 6. - Thrust parameter at optimum inlet conditions.

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